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Jerk analysis in rail vehicle dynamics☆

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Summary The acceleration and deceleration of trains are essential for satisfactory performance of train services and for effective utilisation of line capacity by railways for a given network. However, it increases the risk of unbalancing the passengers. Therefore, in this paper, the jerk was analysed in the vehicle in order to examine its effect on safety and comfort to the passengers. For the purpose of this analysis, a rake with 24 ICF coaches fitted with CBC (H type tight lock) and low preload draft gear hauled by WDP4 locomotive was considered. It was modelled using Universal Mechanism — a multibody dynamic software. Also, in addition, the vehicle is considered to be subjected to external forces such as rolling resistance, longitudinal wheel resistance, and gravitational force. The tractive and braking efforts for the locomotives are also considered with realistic track conditions between Lucknow and Kanpur of India. The presented results suggest that the CBC with balanced type draft gear reduces the jerk in the train.

Introduction

The longitudinal acceleration (acc) and deceleration between two consecutive vehicles of a train effectively determine train composition. It affects train length, traction power requirement, load capacity and permissible speed, particularly for passenger trains. Unscientific decisions relating to these parameters result in increased risk of accidents due to derailments and other train disruptions (Swaroop, 2011). The introduction of Centre Buffer Coupler (CBC) in Indian Railways (IR) led to the problem of longitudinal jerks. Various measures taken to deal with this problem did not result in significant improvement. Research Design and Standard Organisation (RDSO) has done a comprehensive analytical study of the causes of longitudinal jerks. Based on the findings, it has been concluded that the use of a balanced type of draft gear for coaching stock can reduce jerk in the train. Accordingly a new specification of CBC with balanced type draft gear has been developed (Swaroop, 2011). The purpose of this paper was to examine the longitudinal acceleration and jerk values for 24 ICF coaches fitted with CBC (H type tight lock) and low preload draft gear hauled by WDP4

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locomotive. This study was conducted in different phases of the braking conditions, i.e. service brake, auxiliary brake, and emergency brake.

Mechanical model of the train

To examine the longitudinal acceleration and jerk for the train under traction and braking conditions, the general model of the train coaches, connected via coupler device was considered as shown in Fig. 1. In this model, the forces acting on each coach in the train body are forces acting in train — i.e. braking forces (F_{bfi}), inertia force (F_{ii}), rolling resistance force $R_i(v, t)$ and forces due traction/braking effort (Ft) in the locomotive vehicle. The masses of locomotive and coaches were m_1 to m_n, where m_1 is a mass of locomotive.

The braking force for the vehicle was determined based on Eq. (1) (Crăciun and Mazilu, 2014):

$$F_{bfi}(t) = \frac{\mu_a m_i g}{P_{cf\,\max}} p_{cf,i}(t) \tag{1}$$

where $p_{cf\,\max}$ is the brake cylinder maximum pressure, μ_a is the wheel—rail adhesion coefficient, and $p_{cf,i}$ is the brake cylinder instantaneous pressure.

The coupler (CBC-H type tight lock with low preload draft gear) with a tight lock head (AAR type H) with drawbar, drawbar guide (support) and draft gear (draw and buffing gear) was considered (Colin, 2006). The mathematical modelling for draft gear was mainly aimed to establish a relationship between the coupler forces and its relative displacement during train braking. In the under mentioned Eq. (2), ka is a constant which depends on upon the elasticity of the material and kfr is frictional spring coefficient. Moreover, the coupler system consisted of a tight lock at the coupler head and was subjected to a preload for holding the adjacent coupler head which is denoted by P. Thus, Eq. (2) is used to evaluate the coupler forces (2). Their characteristics for the stroke is mainly depend on relative displacement and velocity between neighbouring vehicles:

$$F(\Delta x, \Delta\dot{x}) = \begin{cases} k_{ab}\Delta x + k_{frb}\,|\Delta x_i|\tanh(u\,\Delta\dot{x}) + P & \text{for } \Delta x < 0, \\ P & \text{for } \Delta x = 0, \\ k_{ad}\Delta x + k_{frd}\,|\Delta x_i|\tanh(u\,\Delta\dot{x}) + P & \text{for } \Delta x > 0 \end{cases} \tag{2}$$

Finally, the rolling resistance determined by given Eq. (3) (Jain, 2013):

$$R_i = m_i g r v_i \tag{3}$$

where rv_i and g is the specific resistance and gravitational acceleration respectively.

Simulation study: longitudinal train modelling

In this section, the simulation analysis was conducted to evaluate the longitudinal jerk in different conditions in multibody dynamics software universal mechanism, i.e. at the start, stop and during the transition. The effect of longitudinal acceleration and jerk was seen on four different coaches, i.e. first coach, fifth coach, 14th coach and last coach. Simulation train model is configured as per given in Fig. 2 (''12230/Lucknow Mail,'' 2016).

The train consisted of a locomotive (Loco-WDP 4 of 80.1 ton (t)), B1 to B5 (AC three tier class sleeper coaches 51.36 t), A1 to A4 (AC second class sleeper coaches of 48.80 t), S1 to S9 (non-AC sleeper coaches of 45.30 t), SLR (luggage van of 36.5 t), GS1 and GS2 (generator cum luggage and brake van of 49.10 t). The track between Kanpur to Lucknow in India was considered for the simulation. Track profile for elevation was taken from RDSO (''12230/Lucknow Mail,'' 2016). The traction and braking process began in the different modes at different time in simulation, i.e. 0—50 s was traction mode followed by auxiliary brake with lap mode at 85 s, service brake at 120 s with final brake cylinder pressure of 5.2 kg/cm^2, Brake release at 150 s and at 175 s emergency brake were applied to stop the train. The speed of propagation of air in the brake line (the so-called wave speed braking) was considered as 250 m/s. As a result, the start and the end of the braking process were not simultaneous in all coaches. Moreover, the coupler model, braking model, and rolling resistance model were already discussed in the second section.

Results and discussion

The train was simulated for different braking conditions. Further, these braking phases led to changes in acceleration as well as in jerk, which has been observed at starting,

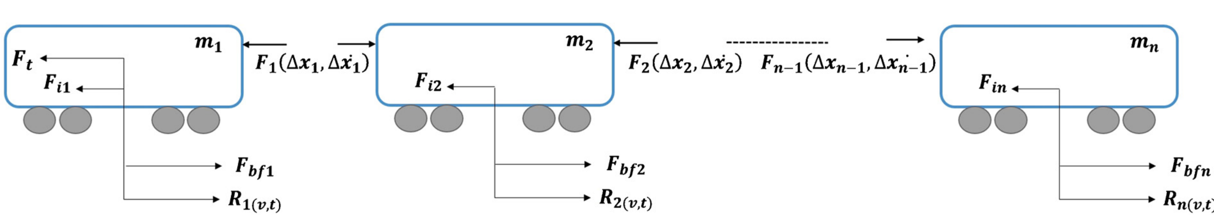

Figure 1 Forces acting in the train.

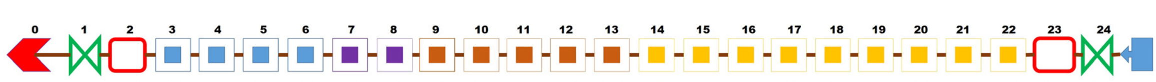

Figure 2 Arrangement of coaches in Lucknow Mail (ICF) rake.

Table 1 Acceleration and jerk values for various phases.

	First coach		Second AC tier		Sleeper coach		Last coach	
	Acc (m/s^2)	Jerk (m/s^2)	Acc (m/s^2)	Jerk (m/s^2)	Acc (m/s^2)	Jerk (m/s^2)	Acc (m/s^2)	Jerk (m/s^2)
Start	0.44	3.41	0.29	3.00	0.37	2.42	0.21	0.64
Tran	0.95	18.9	0.81	13.52	0.45	4.24	1.14	8.58
Stop	0.23	8.99	0.48	9.92	1.07	21.58	0.40	12.66

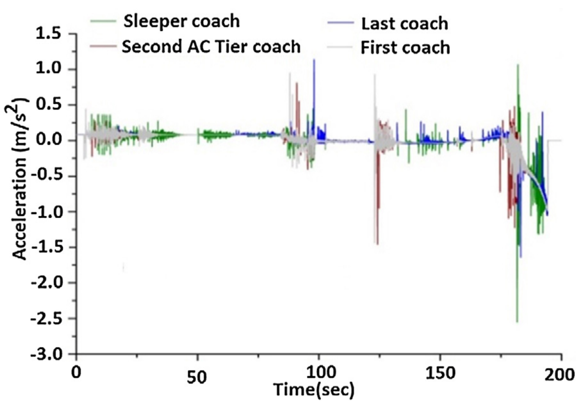

Figure 3 Acceleration response of the train.

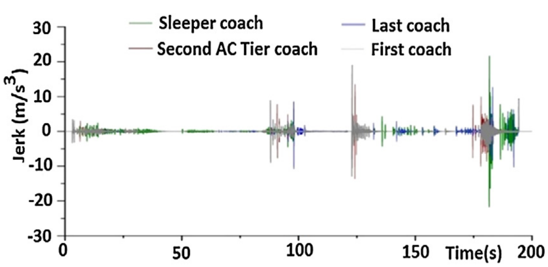

Figure 4 Jerk response of the train.

transition and stopping of the train as shown in Figs. 3 and 4, respectively.

Table 1 shows the acceleration and jerk value for the different phases. The maximum longitudinal acceleration was 1.14 m/s^2 in a transition phase. This was due to different braking phases, i.e. when brakes were applied to the train, coaches progressively impacted with each other as the train compressed. Moreover, the maximum jerk was found when the train was stopped via emergency brake which was 21.58 m/s^2. This brake led to sudden deceleration amongst the coaches in order to stop the train, which resulted in the increased jerk to the passengers.

Conclusion

The passengers felt a different level of jerks due to longitudinal accelerations as per their physiology and psychology. It varied significantly among the passengers the magnitude of jerk depended on the rate of the acceleration. Acceleration and jerk limits were given as single figure in rolling stock specifications. The paper suggested that by using improved CBC pre-draft gear the magnitude of jerk can be reduced and passenger comfort can be improved. The values of jerk were within acceptance limits as prescribed by RDSO.

Conflict of interest

None declared.

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